States, France, Belgium, Germany, Austria, Italy, and Russia, together with the microscopical, botanical, and zoological journals of those countries. It will be obvious to anyone who will compare the last few numbers of the Journal with the first volume, from which we have just quoted, that the former are no less superior to it in general excellence than it was to its immediate predecessors. The editors have elaborated their scheme with the growth of the Journal, and have, in their desire to satisfy the public, gone beyond the prescribed limits, and incorporated abstracts of all the more important papers in certain branches of the science, whether microscopical or not.

In no period of the history of biological science has advance been so rapid as within the last decade, and it is no exaggeration to say that the Journal before us is a faithful historical record of the work done during that period, in those branches with which it professes to deal. To him who would labour in earnest at a given subject the original monographs are indispensable; but even the narrowest of specialists must obtain some knowledge of the advance made in cognate branches of his science, and a ready means of acquiring this, as it applies to microscopy, has been provided by the Journal named during the period of which we write.

It might naturally be supposed that the increase in native workers, whose labours have so far extended the literature of the science and consequently swelled the pages of the Journal in which that literature has been abstracted, must have resulted in a corresponding increase in the circulation of the Journal itself. This, we are informed, has not been the case. In reflecting upon this fact we must remember that during the past decade many changes have been wrought in the literature of biological science. Anzeigers and Records have been established and augmented. But withal the "Notes and Memoranda" of the Society's Journal have made a place for themselves in the library of the working biologist; the abstracts are up to date, and frequently fairly detailed, and they are invaluable to workers who, though not actual specialists, are so placed as to be beyond reach of a good reference library.

The Journal is primarily a microscopical one, and such it must continue to be under the Charter of the Society whose organ it is. Supplemental matters are added by courtesy; but we believe the editors would do well to restrict themselves to purely microscopical matters. In these days of profuse literature showered upon us from all parts of the globe, it is highly desirable that the aims and scope of all journals should be clearly defined and adhered to, if only by way of enabling the worker to know approximately where to turn in search of information upon a given subject. Much has been done of late in this direction by other Societies, and we submit the suggestion to the executive of the one whose Journal we are considering, in full assurance that in restricting their labours as indicated they will be still further contributing to the utility and success of their venture. We would also suggest that pains might occasionally be taken to set forth more fully than hitherto the precise vantage gained by authors quoted, to the exclusion of purely historical *résumés* and details of minor importance. The vital points of a paper are occasionally sacrificed to the reproducing of descriptions of insignificant structural details; and attention to this point would, we believe, enhance the value of the abstracts without in any way lengthening them. Further, work in the native tongue has not always received that attention which it merits.

The editorship of the Journal could not be in better hands than at present. Officers of the Society and all engaged have laboured indefatigably, and they deserve unstinted praise in the execution of their somewhat thankless task. Under the present editorship the Journal has attained a definite and responsible position, beyond that which it occupies as the organ of a chartered Society; its pages are quoted as authoritative records, and we would fain see it more widely disseminated than at present. It is pre-eminently a microscopical journal for workers; it stands unique in its combined features, and is second to none extant in its dealing with the *technique* and optics of the subject. If it is deemed worthy of the formulæ of Abbé, and of orginal articles by the President of the Royal Society, it is deserving of maintenance at the hands of English-speaking people.

## *BRIDGING THE FIRTH OF FORTH.*[1]

DURING the past four years many thousands of visitors from all parts of the United Kingdom, and, indeed, I may say from all parts of the world, have more or less carefully inspected the works now in progress under the superintendence of Sir John Fowler, the engineer-in-chief, and myself, for bridging the Firth of Forth. All classes of visitors, whether possessed of technical knowledge or not, have found at least something to interest them amongst the multifarious operations incidental to carrying out so gigantic an undertaking; and I should have little fear of interesting my present audience if I could change the scene from Albemarle Street to the shores of the Forth. That is impossible, so I must rest content with an imperfect attempt to convey to you, by description and illustration, some notion of the magnitude of the proportions and difficulties of construction of what is generally admitted to be one of the most important engineering works yet undertaken. A "personally conducted" tour over the work would be far more congenial to me than giving a lecture, and infinitely more effective. Photographs, and even the highest efforts of pictorial art, are a poor substitute for the reality. The smallest street accident witnessed by ourselves affects us more than a description or picture of the greatest battle, and for similar reasons I well know that when I speak of men working with precarious foothold at dizzy heights in stormy weather my words will sound very different in this room to what they would were my listeners standing beside me in an open cage hanging by a single wire rope, in appearance like a packthread, and swinging more or less in the wind at a height of between three and four hundred feet above the ground; or were they following me up a ladder as high as the golden cross on the top of St. Paul's Cathedral, with the additional excitement of the rungs of the ladder being festooned with icicles a foot long. You will lose a great deal in vividness of impression necessarily by the substitution of a lecture for a personal visit to the works, but there are some compensating advantages, as you will be saved between eight and nine hundred miles of railway travelling, and a good deal of clambering of the kind shadowed forth.

I should not have thought it necessary to preface my remarks by the statement that the Forth Bridge has nothing to do with the Tay Bridge, had not my four years' experience informed me that about one-half of my fellow-countrymen labour under that singular hallucination. Even at this date I fully expect every second Britisher (of course Americans and foreigners are better informed) to say: "How are you getting on with the Tay Bridge?" I suggest "Forth Bridge," and the correction is generally accepted as a mere refinement of accuracy on my part. As a matter of fact, however, the Tay Bridge which was blown down in 1879, and has since been rebuilt, is at Dundee, whilst the Forth Bridge is near Edinburgh; and as regards type of construction there is nothing in common between the two. If my lecture serves no better purpose, it will at least help, therefore, to disseminate a little useful geographical knowledge respecting the Firths of Forth and Tay.

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[1] Lecture delivered at the Royal Institution, on Friday, May 20, by B. Baker, M. Inst. C.E.

And yet the Forth which "bridled the wild Highlander," and especially that part of it where the bridge crosses, should be well enough known to every reader of fiction, for it has been made the scene of many adventures. Mr. Louis Stevenson's thrilling story, "Kidnapped," will have been read by most of you; the hero of that story was kidnapped at the very spot where the bridge crosses, so I can describe the point of crossing in David Balfour's own words:—

"The Firth of Forth (as is very well known) narrows at this point, which makes a convenient ferry going north, and turns the upper reach into a land-locked haven for all manner of ships. Right in the midst of the narrows lies an island with some ruins; on the south shore they have built a pier for the service of the ferry, and at the end of the pier, on the other side of the road, and backed against a pretty garden of holly-trees and hawthorns, I could see the building which they call the Hawes Inn."

Such was the appearance of the spot 150 years ago. The middle pier of our bridge now rests on the island referred to, and the Hawes Inn flourishes too well, for being in the middle of our works its attractions prove irresistible to a large proportion of our 3500 workmen. The accident ward adjoins the pretty garden with hawthorns, and many dead and injured men have been carried there, who would have escaped had it not been for the whisky of the Hawes Inn.

I would wish if possible now to convey to my hearers some clear impressions of the exceptional size of the Forth Bridge, for even those who have visited the works and noted the enormous gaps to be spanned on each side of Inch Garvie, may yet have gone away without realizing the magnitude of the Forth Bridge as compared with the largest railway bridges hitherto built. For the same reason that architects introduce human figures in their drawings to give a scale to the buildings, do we require something at Queensferry to enable visitors to appreciate the size of the Forth Bridge. If we could transport one of the tubes of the great Britannia Bridge from the Menai Straits to the Forth, we should find it would span little more than one-fourth of the space to be spanned by each of the great Forth Bridge girders. And yet it was of this Britannia Bridge that Stephenson, its engineer, thirty years ago said:—"Often at night I would lie tossing about, seeking sleep in vain. The tubes filled my head. I went to bed with them, and got up with them. In the gray of the morning, when I looked across Gloucester Square, it seemed an immense distance across to the houses on the opposite side. It was nearly the same length as the span of my tubular bridge!"

Our spans, as I have said, are each nearly four times as great as Stephenson's. To get an idea of their magnitude, stand in Piccadilly and look towards Buckingham Palace, and then consider that we have to span the entire distance across the Green Park, with a complicated steel structure weighing 15,000 tons, and to erect the same without the possibility of any intermediate pier or support. Consider also that our rail level will be as high above the sea as the top of the dome of the Albert Hall is above street level, and that the structure of our bridge will soar 200 feet yet above that level, or as high as the top of St. Paul's. The bridge would be a startling object indeed in a London landscape.

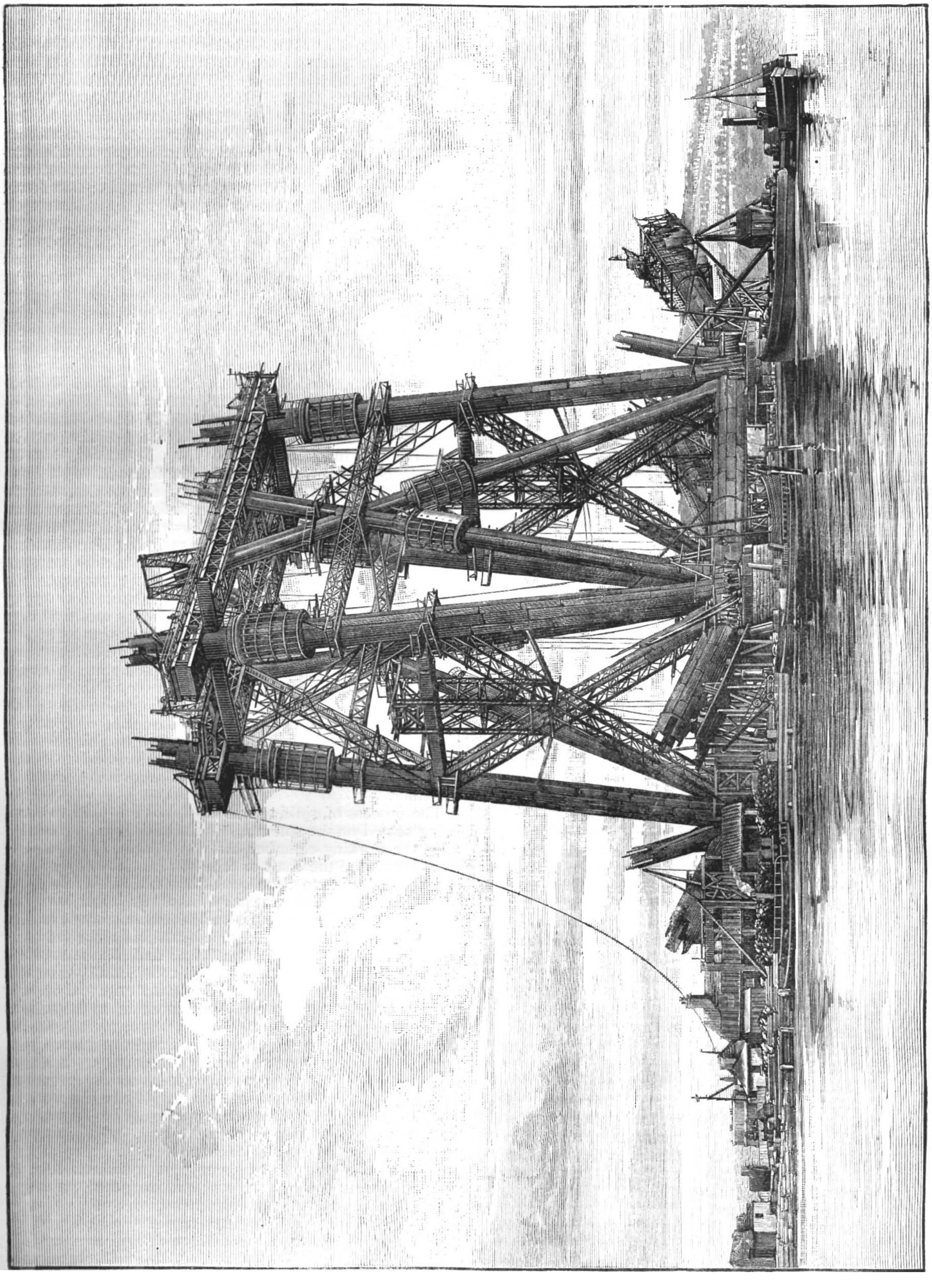
It is not on account of size only that the Forth Bridge has excited so much general interest, but also because it is of a previously little-known type. I will not say novel, for there is nothing new under the sun. It is a cantilever bridge. One of the first questions asked by the generality of visitors at the Forth is, Why do you call it a cantilever bridge? I admit that it is not a satisfactory name and that it only expresses half the truth, but it is not easy to find a short and satisfactory name for the type. A cantilever is simply another name for a bracket. The 1700-feet openings of the Forth are spanned by a compound structure consisting of two brackets or cantilevers and one central girder. Owing to the arched form of the under-side of the bridge, many persons hold the mistaken notion that the principle of construction is analogous to that of an arch. In preparing for this lecture the other day, I had to consider how best to make a general audience appreciate the true nature and direction of the stresses on the Forth Bridge, and after consultation with some of our engineers on the spot a living model of the structure was arranged as follows:—Two men sitting on chairs extended their arms and supported the same by grasping sticks butting against the chairs. This represented the two double cantilevers. The central girder was represented by a short stick slung from one arm of each man, and the anchorages by ropes extending from the other arms to a couple of piles of brick. When stresses are brought on this system by a load on the central girder, the men's arms and the anchorage ropes come into tension and the sticks and chair legs into compression. In the Forth Bridge you have to imagine the chairs placed a third of a mile apart and the men's heads to be 360 feet above the ground. Their arms are represented by huge steel lattice members, and the sticks or props by steel tubes 12 feet in diameter and 1¼ inch thick.

I have remarked that the principle of the Forth Bridge is not novel. When Lord Napier of Magdala accompanied me over the works one day he said: "I suppose you touch your hat to the Chinese?" and I replied "Certainly," as I knew that a number of bridges on the same principle had existed in China for ages past. Indeed, I have evidence that even savages when bridging in primitive style a stream of more than ordinary width, have been driven to the adoption of the cantilever and central girder system as we were driven to it at the Forth. They would find the two cantilevers in the projecting branches of a couple of trees on opposite sides of the river, and they would lash by grass ropes a central piece to the ends of their cantilevers and so form a bridge. This is no imagination, as I have actual sketches of such bridges taken by exploring parties of engineers on the Canadian Pacific and other railways, and in an old book in the British Museum I found an engraving of a most interesting bridge in Tibet upwards of 100 feet in span, built between two and three centuries ago, and in every respect identical in principle with the Forth Bridge. When I published my first article on the proposed Forth Bridge some four years ago I protested against its being stigmatized as a new and untried type of construction, and claimed that it probably had a longer and more respectable ancestry even than the arch.

The best evidence of approval is imitation, and I am pleased to be able to tell you that since the first publication of the design for the Forth Bridge, practically every big bridge throughout the world has been built on the principle of that design and many others are in progress.

PIERS.—Having referred thus briefly to the general principle of the Forth Bridge, I will now describe more particularly the details of the structure, commencing with the piers.

There are three main piers, known respectively as the Fife pier, the Inch Garvie pier, and the Queensferry pier, and upon each of these there are built huge cantilevers stretching both ways. The Fife pier stands between high and low water mark, and is separated by a span of 1700 feet from the Inch Garvie pier, which is partly founded upon a rocky island in mid-stream. Another span of 1700 feet carries the bridge to the Queensferry pier, which is at the edge of the deep channel. The total length of the viaduct is about 1½ mile, and this includes two spans of 1700 feet, two of 675 feet, being the shoreward ends of the cantilevers, and fifteen of 168 feet. Including piers, there is thus almost exactly one mile covered by the great cantilever-spans, and another half-mile of via-



FORTH BRIDGE.—BUILDING THE GREAT STEEL CANTILEVERS.

duct-approach. The clear headway under the centre of the bridge is 152 feet at high water, and the highest point of the bridge is 360 feet above the same datum.

Each of the main piers includes four columns of masonry founded on the rock or boulder-clay. Above low water the cylindrical piers are of the strongest flat bedded Arbroath stone set in cement and faced with Aberdeen granite. The height of these monoliths is 36 feet, and the diameter 55 feet at bottom and 49 feet at top, and they each contain forty-eight steel bolts 2½ inches in diameter and 24 feet long to hold down the superstructure.

Below low water the piers differ somewhat in character, according to the local conditions. On the Fife side, one of the piers was built with the aid of a half-tide dam, and the other with a full-tide dam. The rock was blasted into steps, diamond drills and other rock-drills being used. Even this comparatively simple work was not executed without considerable trouble, as the sloping rock bottom was covered with a closely-compacted mass of boulders and rubbish, through which the water flowed into the dam in almost unmanageable quantity. After many months' work the water was sufficiently excluded by the use of cement-bags, and liquid grout poured in by divers under water, and other expedients, and the concrete foundation and masonry were proceeded with.

At Inch Garvie, the two northernmost piers were founded like the preceding, but the two others presented greater difficulties, owing to the depth of water, and had to be dealt with in a different way. Several designs were prepared for these foundations, but it was finally decided, and, as experience proved, wisely, to put them in by what is known as the pneumatic or compressed air process. The conditions of the problem were a sloping, very irregular, and fissured rock bottom, in an exposed seaway, and with a depth at high water of 72 feet. Anything of the nature of a water-tight cofferdam, such as was used at the shallow piers, was out of question, and the plan adopted was as follows:—

Two wrought-iron caissons, which might be likened to large tubs or buckets, 70 feet in diameter and 50 to 60 feet high, were built on launching-ways on the sloping southern foreshore of the Forth. The bottom of each caisson was set up 7 feet above the cutting edge, and so constituted a chamber 70 feet in diameter and 7 feet high, capable of being filled at the proper time with compressed air to enable men to work as in a diving-bell below the water of the Forth. The caisson, weighing about 470 tons, was launched, and then taken to a berth alongside the Queensferry jetty, where a certain amount of concrete, brickwork, and staging was added, bringing the weight up to 2640 tons. At Inch Garvie a very strong and costly iron staging had previously been erected, alongside which the caisson was finally moored in correct position for sinking. Whilst the work described was proceeding, divers and labourers were engaged in making a level bed for the caisson to sit on. The 16-feet slope in the rock bottom was levelled up by bags filled with sand or concrete. As soon as the weight of caisson and filling reached 3270 tons, the caisson rested on the sand-bags and floated no more. The high ledge of rock upon which the northern edge of the caisson rested was blasted away, holes being driven, by rock-drills and otherwise, under the cutting edge, and about 6 inches beyond for the charges. After the men had gained a little experience in this work, no difficulty was found in under-cutting the hard whinstone rock to allow the edge of the caisson to sink, and, of course, there was still less difficulty in removing the sand-bags temporarily used to form a level bed. The interior rock was excavated as easily as on dry land, the whole of the 70-feet diameter by 7-feet high chamber being thoroughly lighted by electricity. Access was obtained through a vertical tube with an air-lock at the top, and many visitors ventured to pass through this lock into the lighted chamber below, where the pressure at times was as high as 35 lbs. per square inch. Probably the most astonished visitors were some salmon, who, attracted by the commotion in the water caused by the escape of compressed air under the edge of the caisson, found themselves in the electric lighted chamber. When in the chamber the only notice of this escape of large volumes of air was the sudden pervadence of a dense fog, but outside a huge wave of aërated water would rise above the level of the sea, and a general effect prevail of something terrible going on below. No doubt the salmon thought they had come to a cascade turned upside down, and, following their instinct of heading up it, met their fate.

Another astonished visitor was a gentleman who took a flat-sided spirit-flask with him into the caisson, and emptied it when down below. Of course the bottle was filled with compressed air, which exploded when passing through the air-lock into the normal atmospheric pressure, the pressure in the bottle being 33 lbs. per square inch. The Garvie piers, notwithstanding the novelties involved in sinking through whinstone rock, at a depth of 72 feet below the waves of the Forth, were completed without misadventure, in less than the contract time. The first of the deep Garvie caissons was launched on March 30, 1885, and both piers were finished to sea-level or above by the end of the year.

At Queensferry all four piers were founded on caissons identical in principle with those used for the deep Garvie piers. The deepest was 89 feet below high water, and weighed 20,000 tons; the shallowest of the four was 71 feet high, the diameter in all cases, as at Garvie, being 70 feet at the base. Some differences in detail occurred in these caissons as compared with Garvie, owing to the differences of the conditions. Thus, instead of a sloping surface of rock the bed of the Forth was of soft mud to a considerable depth, through which the caissons had to be sunk into the hard boulder-clay. Double skins were provided for the caissons, between which concrete could be filled in to varying heights if necessary, so that greater weight might be applied to the cutting edge where the mud was hard than soft. This annular wall of concrete also gave great strength to resist the hydrostatic pressure outside the caisson, for it must be understood that the water was excluded both below and above the working chamber.

The process of sinking was as follows:—The caisson being seated on the soft mud, which, of course, practically filled the working chamber, air was blown in, and a few men descended the shaft or tube of access to the working chamber in order to clear away the mud. This was done by diluting it to the necessary extent by water brought down a pipe under pressure, and by blowing it out in this liquid state through another pipe by means of the pressure of air in the chamber. It was found that the mud sealed the caisson so that a pressure of air considerably in excess of that of the water outside could be kept up, and it was unnecessary to vary the pressure according to the height of the tide. In working through this soft mud both intelligence and courage were called for on the part of the men, and it is a pleasure and duty for me to say that the Italians and Belgians engaged on the work were never found wanting in those qualifications. There was always a chance of the caisson sinking suddenly or irregularly, and imprisoning some of the men; and, indeed, on one occasion a few men were buried up to their chins in the mud, and on another the caisson gave a sudden drop of 7 feet. Happily no serious accident happened, although I confess that I felt a little apprehensive myself, as I was familiar with the details of an accident with a similar caisson sunk in the bed of the Neva, at St. Petersburg, in 1876. In that case the wet mud rose rapidly in the working chamber when the caisson sank suddenly 18 inches one day, and of the twenty-eight men in the chamber nine remained imprisoned. Of these, two managed to get their heads into the shaft of access, and were taken out alive after twenty-eight hours, and the remaining seven were smothered in the mud. It was nearly a year before sinking was renewed. Again, in 1877, one of the air-locks suddenly gave way, and of the men then in the chamber, three escaped uninjured, nine were blown out by the rush of air, and, falling into the water and on craft, were mortally injured, whilst twenty were smothered in the caisson. It was thirteen months before the chamber was accessible, and then the vitiated atmosphere in the charnel-house below rendered it very difficult to work. Happily we had no such experiences at the Forth.

With one of our caissons we unfortunately had an accident and loss of life, which, although it had nothing to do with the sinking of the caisson, as in the Neva Bridge, was indirectly due to the same cause, viz. the softness of the mud bottom. On New Year's Day, 1885, the south-west Queensferry caisson, which had been towed into position, and weighted with about 4000 tons of concrete, stuck in the mud, and, instead of rising with the tide, remained fixed so that the water flowing over the edge filled the interior. The 4000 tons of water caused the caisson to sink further in the mud, especially at the outer edge, and to slide forward and tilt. The contractors determined to raise the skin of the caisson until it came above water-level, and then pump out and float the caisson back into position. About three months were occupied in doing this, but when pumping had proceeded a certain extent the caisson collapsed, owing to the heavy external pressure of the water, and two men were killed. It was necessary then to consider very carefully what had better be done, as the torn caisson was difficult to deal with. Finally it was determined to case it in "tubbing" of whole balks of timber strutted with ring girders and rakers This was a very tedious work, as every balk had to be fitted water-tight to its neighbours by divers. Finally, on October 19, 1885, or between nine and ten months after the first accident, the caisson, to the relief of everyone, was floated into position and the sinking proceeded without further difficulty, this, the last of the main piers, being completed in March 1886, or almost exactly two years after the first caisson was floated out. No doubt some of my hearers have passed through air-locks and experienced the physiological effects of compressed air, one of the first of which is a painful pressure on the drums of the ears. It is necessary to restrict the hours of work, and even then most men suffer more or less inconvenience. Pains in the limbs are generally relieved by galvanism; a long continuance often leads to paralysis if the depth is great. At the St. Louis Bridge in America, for example, out of 600 workmen who worked in the compressed air, 119 were attacked, 16 died, and 2 were crippled. We had no deaths directly attributable to the air-pressure. Personally I felt no inconvenience whatever. Photographs were taken in the caisson, a total lighting power of 6000 candles and an exposure of as much as 15 minutes in some cases being given. Owing to the fog formed when the air blew under the edge the results were not so good as could be wished, the eyes especially coming out in glaring spectral fashion.

SUPERSTRUCTURE.—I must now say a few words respecting the design, manufacture, and erection of the superstructure.

*Design.*—I have already illustrated the principle of the cantilever bridge, and need only deal with the details. At the Forth, owing to the unprecedented span and the weight of the structure itself, the dead load is far in excess of any number of railway trains which could be brought upon it. Thus the weight of one of the 1700-feet spans is about 16,000 tons, and the heaviest rolling load would not be more than a couple of coal trains weighing say 800 tons together, or only 5 per cent. of the dead weight. It is hardly necessary therefore to say that the bridge will be as stiff as a rock under the passage of a train. Wind, even, is a more important element than train weight, as with the assumed pressure of 56 lbs. per square foot the estimated lateral pressure on each 1700-feet span is 2000 tons, or two and a half times as much as the rolling load. To resist wind the structure is "straddle-legged," that is, the lofty columns over the piers are 120 feet apart at the base and 33 feet at the top. Similarly, the cantilever bottom members widen out at the piers. All of the main compression members are tubes, because that is the form which with the least weight gives the greatest strength. The tube of the cantilever is, at the piers, 12 feet in diameter and 1¼ inch thick, and it is subject to an end pressure of 2282 tons from the dead load, 1022 tons from the trains, and 2920 tons from the wind; total, 6224 tons, which is the weight of one of the largest Transatlantic steamers with all her cargo on board. The vertical tube is 343 feet high, 12 feet in diameter, and about ⅝ inch thick, and is liable to a load of 3279 tons. The tension members are of lattice construction, and the heaviest-stressed one is subject to a pull of 3794 tons. All of the structure is thoroughly braced together by "wind bracing" of lattice girders, so that a hurricane or cyclone storm may blow in any direction up or down the Forth without affecting the stability of the bridge. Indeed, even if a hurricane were blowing up one side of the Forth and down the other, tending to rotate the cantilevers on the piers, the bridge has the strength to resist such a contingency. We have had wind-gauges on Inch Garvie since the commencement of the works, and know, therefore, the character of the storms the bridge will encounter. The two heaviest gales were on December 12, 1883, and January 26, 1884. On the latter occasion much damage was done throughout the country. At Inch Garvie the small fixed gauge was reported to have registered 65 lbs. per square foot, but I found on inspection that the pointer could not travel further, or it might have indicated even higher. I did not believe this result, and attributed it to the joint action of the momentum of the instrument, and a high local pressure of wind too instantaneous in duration to take effect upon a structure of any size or weight. The great board of 300 square feet area on the same occasion indicated only 35 lbs. per square foot, and I doubt much if the pressure would have averaged more than 20 lbs. on so large a surface as the bridge.

*Manufacture.*—The bent plates required for the tubes of the Forth Bridge would, if placed end to end, stretch 42 miles. Special plant had to be devised for preparing these plates. Long furnaces, heated in some instances by gas-producers, and in others by coal, first heated the plates, which were then hauled between the dies of an 800-ton hydraulic press, and bent to the proper radius. When cool, the edges were planed all round, and the plates built up into the form of a tube in the drilling-yard. Here they were dealt with by eight great travelling machines, having ten traversing drills radiating to the centre of the tube, and drilling through as much as 4 inches of solid steel in places. A length of 8 feet was drilled in a day of twenty-four hours. When complete, the tubes were taken down, the plates cleaned and oiled, and stacked ready for erection.

The tension members and lattice girders generally are of angle bars, sawn to length when cold, and of plates planed all round. Multiple drills tear through immense thickness of steel at an astonishing rate. The larger machines have ten drills, which, going as they do, day and night, at 180 revolutions per minute, perform work equivalent to boring an inch hole through 280 feet thickness of solid steel every twenty-four hours. About 4 per cent. of the whole weight of steel delivered at the works leaves it again in the form of shavings from planing-machines and drills. The material used throughout is Siemens's steel of the finest quality, made at the Steel

Company's Works in Glasgow, and at Landore in South Wales. Although one and a half times stronger than wrought iron, it is not in any sense of the word brittle, as steel is often popularly supposed to be, but it is tough and ductile as copper. You can fold half-inch plates like newspapers, and tie rivet-bars like twine into knots. The steel shavings planed off form such long, true, and flexible spirals, that they are largely used for ladies' bracelets when fitted with clasps and electro-plated.

*Erection.*—Facility of erection is one of the most important desiderata in the case of the Forth Bridge. Owing to the 200 feet depth of water, scaffolding is impossible, and the bridge has to constitute its own scaffolding. The principle of erection adopted was, therefore, to build first the portion of the superstructure over the main piers, the great steel towers, as they may be called, although really parts of the cantilever, and to add successive bays of the cantilever right and left of these towers, and therefore balancing each other, until the whole is complete. This being the general principle, a great deal yet remained to be done in settling the details. What was finally settled, and is now in progress, is as follows:—

After the skewbacks, horizontal tubes, and a certain length of the verticals as high as steam-cranes could conveniently reach were built, a lifting-stage was erected. This consisted of two platforms, one on either side of the bridge, and four hydraulic lifting-rams, one in each 12-feet tube. To carry these rams cross-girders were fitted in the tubes capable of being raised so as to support the rams and platform as erection proceeded, and steel pins were slipped in to hold the cross-girders. Travelling cranes are placed on the platforms, and these cranes, with the men working aloft, are of course raised with the platforms when hydraulic pressure is let into the rams. The mode of procedure is to raise the platform 1 foot, and slip in the steel pins to carry the load whilst the rams are getting ready to make another stroke of 1 foot. When a 16-feet lift has been so made, which is a matter of a few hours, a pause of some two or three days occurs to allow the riveting to be completed. The advance at times has been at the rate of three lifts, or 48 feet in height, in a week.

The riveting appliances designed by Mr. Arrol are of a very special and even formidable character, each machine weighing about 16 tons. It consists essentially of an inside and outside hydraulic ram mounted on longitudinal and annular girders in such a manner as to command every rivet in the tubes, and to close the same by hydraulic pressure. Pipes from the hydraulic pumps are carried up inside the tubes to the riveters, and oil furnaces for heating the rivets are placed in convenient spots, also inside the tubes. By practice, and the stimulus of premiums, the men have succeeded in putting in 800 rivets per day with one of the machines, at a height of 300 feet above the sea, which, in fact, is more than they accomplished when working at ground level. Indeed, by the system of erection adopted, the element of height is practically annihilated, and with ordinary caution the men are safer aloft than below, as in the former case they are not liable to have things dropped on their heads.

The cantilever will be erected and riveted in precisely the same manner as the great towers, but owing to the overhang temporary ties will occasionally be required. The centre girder itself will be similarly erected, one half being temporarily added on to the extremity of each cantilever, and when the two ends meet at the centre of a 1700-feet span they will be connected, and the temporary joints, with the cantilevers, released. Roller joints are provided at the cantilever ends for expansion, and at the main piers the whole superstructure rests on lubricated sliding bed-plates.

The system of erection by overhanging offers great advantages as regards safety, as each successive part of the superstructure is riveted up and completed before a further portion is added. In the case of an ordinary bridge the whole superstructure must first be temporarily bolted up on scaffolding, and in that condition is liable to be swept away by flood or hurricane at any moment.

There is nothing new under the sun, and therefore you will not be surprised to hear that in 1810, a certain Mr. Pope proposed to construct a cantilever bridge, of 1800 feet span, across the East River, in New York, and, indeed, exhibited a 50-feet model of the same.

I have described the process of erecting the Forth Bridge in sober prose; if I had thought of doing it in verse I should have appropriated bodily Mr. Pope's lyrical version of his intended operations at the East River, of which the following is a sample:—

> "Each semi-arc is built from off the top,
> Without the aid of scaffold, pier, or prop;
> By skids and cranes each part is lowered down,
> And on the timber's end grain rests so sound.
> Sure all the bridges that were ever built,
> Reposed their weight on centre, pier, or stilt;
> Not so the bridge the author has to boast,
> His plan is sure to save such needless cost;
> A ladder on each side is lowered down,
> And shifted from the fulcrum to the crown."

To carry out the work at the Forth Bridge there is an army of 3500 workmen, officered by a proportionate number of engineers. Everything, except the rolling of the steel plates, is done on the spot, and consequently there are literally hundreds of steam and hydraulic engines and other machines and appliances too numerous to mention, many of them being of an entirely original character.

It is, of course, impossible to carry out a gigantic work of the kind I have had the honour of bringing before the Institution without paying for it, not merely in money, but in men's lives. I shall have failed in my task if you do not, to some extent, realize the risks to which zealous and plucky workmen will be sure to expose themselves in pushing on with the work of erecting the Forth Bridge. Speaking on behalf of the engineers, I may say that we never ask a workman to do a thing which we are not prepared to do ourselves, but of course men will, on their own initiative, occasionally do rash things. Thus, not long ago a man trusted himself at a great height to the simple grasp of a rope, and his hand getting numbed with cold he unconsciously relaxed his hold and fell backwards, a descent of 120 feet, happily into the water, from which he was fished out little the worse after sinking twice. Another man going up in a hoist the other day, having that familiarity with danger which breeds contempt, did not trouble to close the rail, and, stumbling backward, fell a distance of 180 feet, carrying away a dozen rungs of a ladder with which he came in contact, as if they had been straws. These are instances of rashness, but the best men run risks from their fellow-workmen. Thus a splendid fellow, active as a cat, who would run hand over hand along a rope at any height, was knocked over by a man dropping a wedge on him from above, and killed by a fall of between one and two hundred feet. There are about 500 men at work at each main pier, and something is always dropping from aloft. I saw a hole 1 inch in diameter made through the 4-inch timber of the staging by a spanner which fell about 300 feet, and took off a man's cap in its course. On another occasion a dropped spanner entered a man's waistcoat and came out at his ankle, tearing open the whole of his clothes, but not injuring the man himself in any way.

Happily, there is no lack of pluck amongst British workmen; if one man falls another steps into his place. Difficulties and accidents necessarily occur, but like a disciplined regiment in action we close up the ranks, push on, and step by step we intend to carry on the work to a victorious conclusion.